Aerosol and cloud related products by ESA’s Aeolus mission

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Overview

1. Motivation for ESA’s wind lidar mission

2. The Aeolus Doppler Wind Lidar Mission
   a. Aeolus aerosol and cloud monitoring capabilities
   b. Aeolus vs. Calipso/ATLID

3. Cal/Val

4. Conclusions
Atmospheric Dynamics Mission - Aeolus

It’s a Doppler Lidar Wind mission ... ... providing valuable info on aerosols and clouds!

Launch date: spring 2014
Why launch a space-based DWL?

1. There is a need for *homogeneous* global direct measurements of wind profiles, in order to improve the analysis of the atmospheric state for NWP and Climate modelling.

2. Aeolus shall demonstrate the capabilities of space-based HSR Doppler Wind LIDARs (DWLs) for global wind profiling and their potential for operational use.

Global Observing System (GOS) wind information:
- **Radiosonde and pilot** soundings – left (BUT NH continents dominate)
- **Aircraft data** (BUT NH densely populated areas dominate)
- **Satellite soundings** of temperature and humidity from Polar orbiting satellites (BUT indirect measure of large-scale phenomenon wind outside the tropics through geostrophic balance)
- **Atmospheric motion vectors** (BUT only in the presence of clouds)
Why 6pm crossing time?

1) Solar panels almost always illuminated (power for the laser)
2) Largely reduced thermal stress (stability of environment)
Wind and atmospheric optical properties profile measurements are derived from the Doppler shifted signals that are back-scattered by aerosols and molecules along the lidar line-of-sight (LOS).
UV lidar (355 nm, circularly polarized)

Separate molecular and a particle backscatter receivers (High Spectral Resolution)

No polarization measurements

Adjustable vertical sampling of 24 atmospheric layers with thicknesses from 0.25 – 2 km

One observation is made of lidar signals accumulated over 12 sec (i.e. 90 km).

The horizontal measurement granularity within each observation is commendable (3 to 7 km).
### Aeolus vs. Calipso/ATLID: some figures

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Aeolus/Aladin</th>
<th>ATLID</th>
<th>Calipso/Caliop</th>
</tr>
</thead>
<tbody>
<tr>
<td>Satellite altitude</td>
<td>408 km</td>
<td>409 km</td>
<td>705 km</td>
</tr>
<tr>
<td>Orbital inclination</td>
<td>90 deg</td>
<td>97 deg</td>
<td>98 deg</td>
</tr>
<tr>
<td>Ascending node</td>
<td>18:00</td>
<td>14:00</td>
<td>13:30</td>
</tr>
<tr>
<td>Repeat cycle</td>
<td><strong>109</strong> orb/7d</td>
<td><strong>389</strong> orb/25d [nom]</td>
<td><strong>233</strong> orb/16d</td>
</tr>
<tr>
<td>Orbits per day</td>
<td>16</td>
<td>15.6 / 11.6</td>
<td>15</td>
</tr>
<tr>
<td>Laser Divergence</td>
<td>12 µrad / ≈ 6 m</td>
<td>&lt; 30 m</td>
<td>100 µrad / ≈ 70 m</td>
</tr>
<tr>
<td>Telescope Divergence</td>
<td>19 µrad / ≈ 9 m</td>
<td>&lt; 30 m</td>
<td>130 µrad / ≈ 90 m</td>
</tr>
<tr>
<td>Laser Wavelength</td>
<td>355 nm</td>
<td>355 nm</td>
<td>532 nm</td>
</tr>
<tr>
<td>Laser Pulse Energy</td>
<td>120 mJ</td>
<td>34 mJ</td>
<td>110 mJ</td>
</tr>
<tr>
<td>Laser Pulse Length</td>
<td>30 ns</td>
<td>30 ns</td>
<td>20 ns</td>
</tr>
<tr>
<td>Repetition Rate</td>
<td>50 Hz</td>
<td>50 Hz</td>
<td>20 Hz</td>
</tr>
<tr>
<td>Single Shot Distance</td>
<td>140 m</td>
<td>140 m</td>
<td>380 m</td>
</tr>
</tbody>
</table>
1. **Primary (L2b) product:**
   Horizontally projected LOS wind profiles
   - Approximately zonal at dawn/dusk
   - 3 km-averaged measurements and ~90 km averaged observations – scene classified
   - Random errors (m/s): 1 (PBL), 2 (Trop), 3-5 (Strat)

1. **Secondary (L2a) products:**
   Optical properties profiles:
   - $\beta$, $a$, OD, scattering ratio
   - Aerosol typing (backscatter-to-extinction ratio)
   - Cloud/aerosol cover/stratification
   - Cloud/aerosol top heights
   - Cloud/aerosol base height (optically thin)
Optical architecture of ALADIN.

Cross-talk (Mie -> Rayleigh and Rayleigh -> Mie)

- **Mie receiver:** fringe imaging Fizeau spectrometer
- **Rayleigh receiver:** double edge Fabry-Pérot etalon
For each observation, ADM provides two signals, one Rayleigh, one Mie, related to the optical parameters of the atmosphere via the equations:

\[
S_{\text{Ray}}(z) = K_{\text{Ray}} \left[ C_1 \beta_{\text{mol}}(z) + C_2 \beta_{\text{aer}}(z) \right] \frac{\Gamma_{\text{mol}}^2(z)\Gamma_{\text{aer}}^2(z)}{R^2(z)}
\]

\[
S_{\text{Mie}}(z) = K_{\text{Mie}} \left[ C_3 \beta_{\text{mol}}(z) + C_4 \beta_{\text{aer}}(z) \right] \frac{\Gamma_{\text{mol}}^2(z)\Gamma_{\text{aer}}^2(z)}{R^2(z)}
\]

where \(C_1, C_2, C_3, C_4, K_{\text{ray}}\) and \(K_{\text{mie}}\) are known calibration constants (\(C_1 \sim C_2; C_3 \ll C_4\)).

**In principle**, it is possible to determine \(\alpha_{\text{aer}}(z)\) and \(\beta_{\text{aer}}(z)\) from the equations above.

**In practise**, difficulties are encountered due to:

- The lidar **cannot distinguish absorption and scattering** extinction
- **Large thickness of the height bin** (vertical inhomogeneity give ambiguous results when solving the lidar equation)
- Dependence on a priori **temperature** and **pressure** information
- Only way to discriminate **aerosol** versus **cloud** particles: use \(\beta/\alpha\)

(by A. Dabas, MeteoFrance)
SCA: standard correct algorithm
“Normalized Integrated Two-Way Transmission (NITWT)” assuming a **uniform particle layer filling** of the entire range bin.

ICA: iterative correct algorithm is intended to retrieve both, the location of the layer in the range gate and the local optical depth when accounting for **partial layer filling** of the range bin.

MCA: Mie channel algorithm, uses Mie channel data and climatology when **no valid Rayleigh data are available**
Aeolus vs. Calipso/ATLID: vertical resolution

<table>
<thead>
<tr>
<th>Layer (km)</th>
<th>Resolution in km</th>
</tr>
</thead>
<tbody>
<tr>
<td>30 – 40</td>
<td>0.30</td>
</tr>
<tr>
<td>20 – 30</td>
<td>0.18</td>
</tr>
<tr>
<td>8 – 20</td>
<td>0.06</td>
</tr>
<tr>
<td>0 – 8</td>
<td>0.03</td>
</tr>
<tr>
<td>-2 – 0</td>
<td>0.30</td>
</tr>
</tbody>
</table>

Calipso

ATLID: 0.1 km

Finer grid (0.5 km) for Mie channel below 3 km
Aeolus: Why only 24 range bins?

Image Zone
- 16 x 16 pixels, 27 μm each

Transfer Row

Memory Zone
- 25 rows with 32 elements, alternating transfer and storage cells

Signal readout:
- After a n accumulation period (15 or 50 lidar pulses), the storage columns are pushed down into the readout register, and there shifted to the output amplifier to generate a video signal. After readout of all rows, the storage columns are cleared to prepare for the next accumulation sequence.

Single lidar return:
- For each height interval, contents of the transfer columns in the memory is pushed one row down, and the transfer row is cleared. Then the image zone is summed into transfer row.
- Result is the height binned lidar return in transfer columns of the memory zone.

Signal accumulation:
- After the lidar pulse, the contents of the transfer columns is shifted by one column and added to the storage columns.
- After accumulation, the transfer columns are cleared to prepare for the next lidar acquisition.
## Aeolus ("measurement") vs. Calipso/ATLID: horizontal resolution

<table>
<thead>
<tr>
<th>Layer (km)</th>
<th>Aeolus (km)</th>
<th>Calipso (km)</th>
<th>ATLID (km)</th>
</tr>
</thead>
<tbody>
<tr>
<td>30 – 40</td>
<td>-</td>
<td>5.00</td>
<td>0.28</td>
</tr>
<tr>
<td>20 – 30</td>
<td>3 to 7</td>
<td>1.67</td>
<td>0.28</td>
</tr>
<tr>
<td>8 – 20</td>
<td>3 to 7</td>
<td>1.00</td>
<td>0.28</td>
</tr>
<tr>
<td>0 – 8</td>
<td>3 to 7</td>
<td>0.33</td>
<td>0.28</td>
</tr>
<tr>
<td>-2 – 0</td>
<td>3 to 7</td>
<td>0.33</td>
<td>0.28</td>
</tr>
<tr>
<td>Mission</td>
<td>Spatial sampling</td>
<td>Particle layer detection</td>
<td>Optical properties</td>
</tr>
<tr>
<td>-------------</td>
<td>----------------------------------------------------------------------------------</td>
<td>------------------------------------------------------------------------------------------</td>
<td>---------------------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>ADM-Aeolus</td>
<td><strong>Limited</strong> vertical resolution in range bins equal to .25, .50, 1 and 2 km.</td>
<td><strong>Good</strong>. The Mie channel performs well at moderate SNR (≥ 10)</td>
<td><strong>Good</strong> based on HSRL capability to derive particle local optical depth per range bin $LOD_p$ and extinction-to-backscatter ratio $EBR$ using the Rayleigh and Mie channels</td>
</tr>
<tr>
<td>CALIPSO</td>
<td><strong>Good</strong>. Vertical sampling at high resolution provides flexibility. Accumulation to improve SNR.</td>
<td><strong>Good</strong> SNR &gt; 10</td>
<td><strong>Limited</strong>. Colour ratio using 2 wavelengths and depolarization ratio are provided. But <em>a priori</em> knowledge of $EBR$ is required to compute $LOD_p$ or backscatter or extinction coefficient</td>
</tr>
</tbody>
</table>

$LOD = $ local optical density; $EBR = $ extinction-to-backscatter ratio (1/ BER)

WAC = wide angle camera; IIR = infrared imager
Some of the ADM Cal/Val tasks

1. Assessment, characterization of radiometric performance and stability
2. Validation of geo-location information
3. Recommendations for enhancements of algorithm and observational settings
4. Systematic validation of algorithms from L1A to L1B and L2A and L1B to L2B
5. Validation of stability of instrument calibration

ICAP 2012, ESRIN, 15 May 2012
Wind:
Ground based DWL, HSRL, Radars, Sondes (troposphere-stratosphere), Airborne DWL, NWP models

Aerosols/Clouds
Airborne-backscatter Lidars, ground-based Lidars (including Raman), sondes
Campaigns:


b. So far, on the order of 100 recommendations for the Aeolus mission (instrument and algorithm development and testing)

c. Phase E1 (commissioning, ESTEC) and phase E2 (operation, ESRIN) campaigns will be defined soon
1. The platform was completed in 2009 and in storage; modifications for In-situ Cleaning System required
2. The Aeolus ALADIN Lidar subsystems have all been delivered and qualified on subsystem level, but some modifications are required for an In-situ Cleaning System (flow of O\textsubscript{2} at very low pressure)
3. The transmitter laser is the most challenging for the qualification
   a. Laser development & qualification status reviewed by external expert team. Recommendations being implemented:
      – Continuous mode operation
      – Harmonic section to be optimized
   b. Continuous Mode operation:
      – Delta Critical Design Review concluded in March ‘11
1. Aeolus wind lidar mission will deliver atmospheric optical properties measurements as secondary products (L2a)

2. The Aeolus L2a products will be made available to users off-line (now every 12 hours) but could in the future become available every 4 hours or more often

3. Aeolus L1b products will be available to users NRT and could be further processed locally

4. Launch scheduled for spring 2014
Thank you for your attention!
Spare I: range bins adapted to surface elevation variations

Extra-tropical scenario

Tropical scenario

Tropical scenario – no calibration

Terrain-Following model

Co-location of Mie and Rayleigh channel sampling within an observation is essential

ICAP 2012, ESRIN, 15 May 2012
The **Scene Classification Algorithm** shall classify the types of aerosol and cloud scenes occurring within each observation.

The classification shall be used to distinguish backscatter from aerosols, water clouds and ice clouds in each range bin.

\[
\text{Classification}_{i} = \text{Class}_{BER}_{i} + 2 \times \text{Class}_{Rsc}_{i} + 4 \times \text{Class}_{Temperature}_{i}
\]

\[
\text{Class}_{BER} = 0 \text{ if BER < 0.1; } = 1 \text{ otherwise}
\]
\[
\text{Class}_{Rsc} = 0 \text{ if Rsca < 1.5; } = 1 \text{ otherwise}
\]
\[
\text{Class}_{Temperature} = 0 \text{ if } T < 237.15K; = 2 \text{ if } T > 273.15K; = 1 \text{ otherwise}
\]
### Spare III: scene classification

<table>
<thead>
<tr>
<th>BER classification</th>
<th>Scattering ratio classification</th>
<th>Temperature classification</th>
<th>Index of Classification</th>
</tr>
</thead>
<tbody>
<tr>
<td>#1</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>#2</td>
<td>1</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>#3</td>
<td>0</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>#4</td>
<td>1</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>#5</td>
<td>0</td>
<td>0</td>
<td>4</td>
</tr>
<tr>
<td>#6</td>
<td>1</td>
<td>0</td>
<td>5</td>
</tr>
<tr>
<td>#7</td>
<td>0</td>
<td>1</td>
<td>6</td>
</tr>
<tr>
<td>#8</td>
<td>1</td>
<td>1</td>
<td>7</td>
</tr>
<tr>
<td>#9</td>
<td>0</td>
<td>2</td>
<td>8</td>
</tr>
<tr>
<td>#10</td>
<td>1</td>
<td>2</td>
<td>9</td>
</tr>
<tr>
<td>#11</td>
<td>0</td>
<td>2</td>
<td>10</td>
</tr>
<tr>
<td>#12</td>
<td>1</td>
<td>2</td>
<td>11</td>
</tr>
</tbody>
</table>

- **Small particles**: No features in this layer, or very few.
- **Big particles**: Features in this layer.
- **Ice crystals, Cirrus Clouds, Mixed phase clouds, Water droplets**
- **Aerosol layers**
• The two FP band-passes FP-A and FP-B have a FWHM = 0.7 pm (or 1.67 GHz) and are separated by 2.3 pm (or 5.47 GHz).

• The free spectral range (FSR) of the Fizeau interferometer is equal to 0.92 pm but only a fraction of it is imaged onto the detector so the useful spectral range is USR = 0.63 pm or 1500 MHz.

• The FWHM of the Fizeau interferometer transfer function is 0.06 pm or about 143 MHz. Each channel has an equivalent spectral width of 93.75 MHz or 17 m/s.
### Spare V: Mie and Rayleigh signals

<table>
<thead>
<tr>
<th>Granularities $ij$</th>
<th>Mie Channel</th>
<th>Rayleigh Channel</th>
</tr>
</thead>
<tbody>
<tr>
<td>Range bin $i$</td>
<td>No signal</td>
<td>No signal</td>
</tr>
<tr>
<td>Range bin $i+1$</td>
<td>No signal</td>
<td>No signal</td>
</tr>
<tr>
<td>Range bin $i-1$</td>
<td>No signal</td>
<td>No signal</td>
</tr>
<tr>
<td></td>
<td>Standard signal</td>
<td>Wea or no signal</td>
</tr>
<tr>
<td></td>
<td>Strong signal</td>
<td>Effective albedo</td>
</tr>
</tbody>
</table>

*Effective albedo*

*Weak or no Bckg*